UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 27 1989

OFFICE OF WATER

MEMORANDUM

SUBJECT: UIC Land Ban Petitions; Common Deficiencies

FROM: Michael B. Cook, Director Michael B Cook
Office of Drinking Water (WH-550)

TO: Water Supply Branch Chiefs
EPA Regions IV, V, VI, and VII

As I indicated to you in recent meetings, my staff has been compiling a summary of common deficiencies encountered by both Headquarters and Regional staff in the initial round of reviews of "no migration" petitions submitted for hazardous waste injection facilities. Most of the deficiencies have been resolved through revisions of the petitions. However, valuable time would be saved if some of the common problems could be avoided in the petitions that are submitted from now on.

Regional and Headquarters staff are encouraged to discuss these deficiencies, and any other technical matters, with the regulated community. Informal phone calls and meetings will expedite the review process by improving communication and resolving any misunderstandings between the Agency, the States, and petitioners.

The attached compilation will first discuss general problems with petitions, and then discuss specific problems. Specific problems have been divided into five catagories: geology, hydrogeology, area of review, modeling, and seismicity. As Headquarters has the responsibility for reviewing the modeling, we have expanded on that discussion.

If you have further questions concerning this matter, please call David Morganwalp at FTS 382-5508 or (202) 382-5508, or send him an E-mail message to Box D.MORGANWALP (EPA4504).

Attachment

Common Petition Deficiencies

General Deficiencies

1.) In general, the petitions need to be better organized. For example, information that is important for proper review of the modeling section is often widely scattered throughout the petition. This makes the review more time-consuming. Tables displaying the values used for modeling with references to the data source would be a valuable tool. Petitioners need to present their argument in a clear manner with some direction and intent in the narrative. A collection of facts that lets the reviewer make the connections is not appropriate for the petition process.

2.) Another general problem is quality control and assurance of not only the data, but of the petition document itself. Several petitioners do not use consistent units to report the thickness and depths of formations in a consistent manner throughout their documents. In other petitions, different values for the thickness and depths of formations are reported in different sections of the petition.

3.) There is a lack of technical details throughout many petitions. All the methods and processes that are used to sustain the no-migration demonstration need to be documented or referenced.

Specific Deficiencies

Geology

Often, this section contains only minimal material (it gets the least amount of attention). Since geologic data is needed to construct the models, there needs to be more documentation and a greater amount of detail. Where assumptions are made about the geology of the regional and local areas, they should be clearly identified and justified. The effect of these assumptions on the no-migration demonstration should be discussed. All statements and conclusions should be supported with references or data from the site. The local geology needs to be tied into the regional geologic setting. Closer attention needs to be paid to maps and cross sections. Supporting logs should be submitted, so that reviewers can assess the interpretations that the maps and cross sections represent. The sedimentology of the injection zone and confining zone needs to be covered and related to the assumption about the permeability distributions of these zones. For example, a channel sandstone cannot be modeled as a homogeneous and isotropic confined aquifer of constant thickness and infinite in horizontal extent, while a beach strand plain sandstone could be.

Hydrogeology

This is another section or area that deserves more attention by petitioners. Many petitions have not covered the hydrology of the USDW, Confining Zone, or the Injection Zone with enough detail. The hydrology should be discussed on both a regional and local scale. A long term (10,000 years) no-migration demonstration hinges on the ground water-flow velocity in both the horizontal and vertical directions. The hydrology of the injection well site should answer the following questions:

1.) What is nature of the regional flow field and local flow field of the USDWs, injection zone, and confining zone?

2.) What is the potentiometric surface of the lower most USDW and the injection interval?

3.) What is the spatial permeability and porosity distribution of the injection zone and the confining zone?

In general, results of transient pressure well-testing should be submitted with the petition. Petitions that rely solely on sidewall cores and log-derived permeability are not adequate. In many cases spinner surveys are also necessary to characterize the behavior of the injection interval. Since there are usually very few data points with which to make a no-migration demonstration, it is very important to get as much information from the injection wells as possible.

A full analysis of the transient pressure test should be included in the petition. The presentation should include the methods used to determine the flow capacity (transmissivity), skin, storage, boundaries, etc., and any Horner plots or other graphical analysis methods.

Area of Review

The Area of Review calculation needs to be based on the simulated pressure results presented in the predictive modeling (a different method can be used if deemed appropriate). The delineation of the area of review, like the delineation of the waste plume, needs to be based on the geology and hydrogeology of the site. Any boundary conditions, pinchouts, facies changes, etc. must play a part in determining the area.

Wells which penetrate the injection zone, and are located within the area of the waste plume movement, must be constructed or plugged to prevent the migration of hazardous waste from the injection zone. This includes any wells that the waste plume might encounter due to regional drift over the 10,000 year demonstration time, where pressures will remain high enough to cause migration out of the injection zone.

Predictive Modeling

There have been deficiencies with the predictive modeling submitted in petitions in the following categories: verification and validation, justification of assumptions, model construction, injection history, other system stresses, conservative approaches, model calibration, molecular diffusion, concentration cut-off, waste plume delineation, sensitivity analysis, and uncertainty analysis.

Verification and Validation

Many petitions are using an assortment of analytical and semianalytical models to make their demonstration. There is nothing wrong with this approach, but some petitioners have assumed that since they are using analytical or semianalytical models they do not need to verify or validate their models. Verification and validation are not limited to numerical models. There are verification and validation procedures that can be applied to analytical and semianalytical models. For example, several petitions are using semianalytical models that are very similar in approach to one that is presented in Javandel, et al, 1984 (RESSQ). These models can be verified and validated by comparing the model's results to simpler analytical models, to Javandel, et al, 1984 (RESSQ), to numerical formulations from well documented codes, and to field data. The references and documentation for all codes (simulators) must be given or referenced in the petition.

Justification of Assumptions

All assumptions must be identified and justified. The justification should include a discussion of the results of the assumptions on the no-migration demonstration. Most petitioners have used more than one model for their no-migration demonstration. This means that a single petition may have several sets of assumptions each pertaining to a particular model. The petitions must clearly indicate which assumptions belong to which model. Another common problem is that the first model that is introduced has an adequate justification of assumptions, but later models do not. With each new model, the assumptions for the model must be discussed. A short discussion on how they differ from the previous model's assumptions would help. A table that summarizes all the assumptions for all of the models would help matters greatly. For example, the table should, as necessary, list the assumptions used for an injection pressure buildup model, a horizontal transport model, a vertical transport model, a long-term horizontal transport model, and a long term vertical transport model. Each one of these models could have a different set of assumptions[1].

Conceptual Models and Model Construction

Several petitions used models which did not address known faults, pinchouts, facies changes, fractures, changes in formation thickness, and/or other characteristics of the site's geology. The no-migration demonstration must be consistent with the geology of the site. However, the model need not be an exact duplication of the site. In formulating the conceptual model of the site, petitions can demonstrate that particular structures (or processes) will not have a significant effect on the no-migration demonstration. For example, a petition can make use of very simplified analytical models to demonstrate that a fault which is located at some distance from the site, will not significantly affect the pressure build-up. That is to say it will not cause the pressure build-up to be asymmetric. The petitioner can then construct a three dimensional numerical model of the site without including the fault.

A distinction should also be made between the total formation thickness and the net thickness that is often used in models. This has caused confusion in the some petitions.

[1] This example is not an endorsement of how to make a no migration demonstration. It is presented here only as an example.

Injection History

Some petitioners have not modeled the entire injection history. Past injection activities have to be taken into account in the demonstration. These past activities have an impact on the current fluid velocity field in the injection and confining zones. This includes intervals where injection took place in the past, but have been closed-off due to a recompletion. Onsite injection wells that have been plugged and abandoned are also candidates for inclusion. The whole time span of injection at the site should be modeled. Injection zones have a memory, because pressure increases are additive.

Other System Stresses

Several petitions have not included the impact of other system stresses on the no-migration demonstration. Other system stresses can be other injection wells on site, other injection well facilities, production wells in oil fields, and/or old injection or production activities that are no longer active. In some cases, the effects of ground-water withdrawals in USDWs also need to be addressed. These stresses can affect the shape and growth of the waste plume in both the horizontal and vertical direction.

Conservative Approaches

There have been many problems with the use of conservative parameters in modeling. A value for a parameter may only be conservative in a given context. For example, a petitioner assigns a "conservative" (i.e. high) value for the permeability of the injection interval. This will give a conservative result if the intent is to model for waste transport in the horizontal direction. However, it will not give a conservative result if the intent is to model for waste transport in the vertical direction, because the high permeability would result in a low pressure build-up, hence short vertical waste transport.

The following are three specific examples of where the use of "conservative" have been and issue. In one petition there were no hard data on the permeability (horizontal or vertical) of the confining zone. The petitioner estimated a value based on a range of values for that region, found in a published source. However, the petitioner picked a value in the middle of the range. This is a case where a value on the high end of the range (a conservative value) should have been picked, in order to yield a "worst case" scenario. In short, parameters with greater uncertainty should be estimated with more conservative values.

Several petitioners have taken a conservative approach, and picked appropriate values for all parameters <u>except</u> porosity. Here the petitioners used a value on the high end of the possible range of data. This will have the opposite effect on the results, because porosity appears in the denominator of transport equations. A low value of porosity must be chosen to get a conservative transport prediction.

Finally, several petitioners used a "multiplying factor", which they applied to the injection rate, to model an injection interval with layered heterogeneity. The "multiplying factor" is defined as,

$$m = \frac{k_m / \phi_m}{k_a / \phi_a},$$

where k_m equals the maximum permeability, ϕ_m equals the maximum porosity, k_a equals the average permeability, ϕ_a equals the average porosity, and m equals the "multiplying factor". Use of this "multiplying factor" is intended to give a conservative result. However, this approach does not take into account the thickness of layers, and might not give a conservative result. For example, if only 25% of the total thickness is receiving 85% of the injected fluid , the plume radius could be much larger than computed using the above "multiplying factor". A better method to assess layered heterogeneity is to use the permeability-thickness product for each layer. This is determined for each layer by the following equation:

$$Q_i = Q_t \frac{K_i h_i}{\sum_{j=1}^{n} K_j h_j}.$$

Here Q_i equals the i^{th} injection rate into the i^{th} layer (L^3/T), Q_t equals the total injection rate, K_i equals the hydraulic conductivity of the i^{th} layer, h_i equals the thickness of the i^{th} layer, K_j equals the hydraulic conductivity of the j^{th} layer, h_j equals the thickness of the j^{th} layer, and n equals the total number of layers. This equation gives the injection profile, which can provide a better estimate of which layer will have the largest waste plume radius. Appropriately conservative parameters can then be used. One of the major problems with the above approach ("multiplying factor") was that it used only the permeability, and not the permeability thickness product (flow capacity or transmissivity). A well test can be used to assess the overall permeability thickness product of a layered injection interval, and a spinner survey can test for the injection profile. The results of these tests can be very different from log-derived permeabilities and sidewall cores. The use of all these tools can lead to an appropriate prediction of what the maximum plume dimensions could be.

Purely advective calculations must take into account dispersion to remain conservative. This can be done by adding an appropriate distance onto the advective calculations. For example the effect of dispersion at the 10^{-6} concentration level can be estimated using the following equation,

$$X = 6.92\sqrt{Dt}$$

where D equals the hydrodynamic dispersion coefficient, and t equals the time, 6.92 is a factor to achieve an estimate for the 10^{-6} concentration level[2], and X is the estimated extra distance due to dispersion. This equation is normally seen in the following form:

$$X = 2\sqrt{Dt}$$

which gives the distances to the 0.3% concentration point.

Model Calibration

Deficiencies associated with model calibration are caused by a lack of detail on the model calibration process. The Agency needs to know what "knobs were turned", and some assurance on the uniqueness of the calibration. More than one set of

[2] The factor 6.92 was based on an analysis of the complementary error function erfc(). The erfc is defined by the following: $\mathrm{erfc}(\beta) = 1 - \frac{2}{\sqrt{\pi}}\int_0^\beta e^{-\xi^2}d\xi$. 10^{-6} was used as an example of a concentration reduction based on health based concentration limits.

parameters, in addition to the site's actual parameters, can result in a pressure history match. This nonuniqueness can be controlled by a sensitivity analysis that is done in conjunction with the model calibration. In this way, the modeler can have a greater level of confidence that the proper "knobs are turned" to achieve a history match.

Molecular Diffusion

Many petitions were submitted or started before the final regulations were promulgated, and therefore do not include molecular diffusion in the no-migration demonstration. All of these petitions will have to include molecular diffusion.

Molecular diffusion can be handled by several different methods. However, petitioners need to provide more detail on the relationship between the area's vertical fluid flow velocity and the coefficient of molecular diffusion. Headquarters staff is currently working on a guidance on molecular diffusion and health-based concentration limits. This should not deter petitioners from submitting models that include molecular diffusion, with their best estimate of what their concentration cut-off should be (a conservative approach might be best at this stage). When the guidance is finished, it will be a simple matter to adjust the final results.

Concentration Cut-Off

Another common deficiency is that predicted concentrations or waste plume boundaries are not based on health-based concentration limits that are appropriate for the injected waste. Typically, concentrations are reported that only represent a 90% or 99.7% reduction in concentration. Agency analysis shows that in many cases 10^{-3} to 10^{-6} concentration reductions are more appropriate. Some petitions have reported the results of their molecular diffusion calculations with the proper concentration reductions, but have not done so with their solute transport calculations (advective-dispersive transport). All delineations of waste plume boundaries need to be based on health based concentration limits.

Waste Plume Delineation

Waste plume boundaries should be predicted throughout time. Areal plume boundaries should be depicted on a base map that has incorporated established landmarks (artificial penetrations, plant boundaries, roads, geologic structures, etc.). In general, not enough attention has been paid to the areal distribution of the injected waste. A vertical profile in a layered case is also helpful to a full understanding of the flow system.

A common method used to track the waste plume's migration is to model it in two stages. First, it is modeled in the near term when the well is active, and then in the long term after the well and has been plugged and abandoned. Modeling in the near term involves predicting what the injection rate will be for the next several years. Many petitioners have used a rate that is very similar to the current rate or slightly lower, because they are working on a waste minimization program. Petitioners should be aware, that they are in effect petitioning to use this new rate as their maximum injection rate. The facility will not be allowed to inject at a higher rate, even if the permit allows a higher rate, because their no-migration demonstration was based on the lower rate. Petitioners should base their predictions of what the future injection rate will be on the maximum allowable, permitted, injection rate.

Short term calculations need to include an analysis of the effect of the regional gradient on plume shape. In most cases, the injection operation completely overwhelms any possible asymmetry of the plume shape, that could be caused by the regional gradient. However, this needs to be demonstrated. In most cases it can be done using simple analytical methods.

Long term calculations, in general, need a more robust analysis presented than has been seen to date in most petitions. The analysis needs to demonstrate no-migration in the horizontal direction as well as the vertical direction. This means that petitioners will have to track the waste plume's areal migration. Of particular importance, are any abandoned wells that the waste plume might encounter.

Sensitivity Analysis

So far, most petitions have lacked a sensitivity analysis. A sensitivity analysis can show what parameters control the waste transport at the site, and can give a "feel" for "best" and "worst" case scenarios. As mentioned above, a sensitivity analysis is a valuable tool that can be used to help with model calibration.

Uncertainty Analysis

In addition to an sensitivity analysis an uncertainty analysis is also a required part of a no-migration demonstration. The petitions need to provide a measure of the uncertainty of the prediction(s). This is done by tying the uncertainties associated with model input parameters to the final prediction. This can be done by error propagation analysis, or using the results of an adjoint sensitivity analysis, or a Monte Carlo analysis. The petitioners must chose the appropriate method to assess uncertainty, based on the amount of parameter uncertainty and the modeling approach.

Seismicity

Most petitioners have done a very good job of addressing the risk due to naturally occurring earthquakes on their operations; however, the risk due to injection induced earthquakes in most cases has not been addressed. Some assessment of the risk of injection induced earthquakes needs to be provided. Some petitioners will have to do a more rigorous demonstration that others depending on the site's geology.